to measuring the flow of a river by putting the float in an eddy near the shore, while the 8,000-meter level is safely below the upper inversion. It is in this region of comparatively uniform changes that seasonal effects are most clearly seen.

TABLE 1.—*Observed vertical temperature gradients between 3,000 and 8,000 meters elevation.*

LINDENBERG.

Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$	Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$
	Meters.	°C.			*Meters.*	°C.	
Aug. 3, 1905...	3,514 7,652	− 7.0 −40.0	0.798	July 5, 1906...	3,000 8,000	1.3 −34.9	0.724
Aug. 29, 1905...	3,000 8,000	− 2.4 −44.5	0.842	Aug. 2, 1906...	3,070 7,810	2.0 −36.7	0.817
Aug. 31, 1905...	3,000 8,000	− 1.0 −27.2	0.524	Sept. 6, 1906...	2,870 8,390	3.2 −28.4	0.572
Jan. 4, 1906...	3,000 8,000	− 4.8 −41.7	0.738	Feb. 7, 1907 ..	3,000 8,000	−14.2 −58.2	0.880
Feb. 1, 1906...	3,000 8,000	− 9.6 −42.4	0.656	July 4, 1907...	3,000 8,000	1.4 −26.6	0.560
July 4, 1906...	3,022 7,782	0.3 −35.3	0.746				

PAVLOVSK.

Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$	Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$
Feb. 9, 1905...	2,280 8,000	−17.8 −50.0	0.642	Feb. 1, 1906...	3,000 5,960	−22.1 −32.7	(0.358)
July 6, 1905...	3,000 8,000	0.9 −30.9	0.636	July. 5, 1906...	3,000 5,820	2.3 −11.7	(0.497)
Aug. 29, 1905...	3,000 8,000	− 4.4 −35.7	0.626	Sept. 6, 1906 ..	3,060 8,000	− 3.6 −36.3	0.662
Aug. 30, 1905..	3,000 8,000	− 4.0 −32.8	0.576	Jan. 14, 1907...	3,000 7,800	−21.0 −47.8	0.670
Jan. 4, 1906...	2,970 8,000	− 8.3 −41.6	0.662	Feb. 7, 1907...	3,000 8,000	−12.6 −49.5	0.738
Mar. 1, 1906...	3,000 8,000	−16.7 −52.5	0.716	Mar. 7, 1907...	3,000 8,020	−15.5 −44.3	0.575

STRASSBURG.

Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$	Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$
	Meters.	°C.			*Meters.*	°C.	
Jan. 5, 1905. .	3,000 8,000	− 4.2 −41.4	0.744	Mar. 1, 1906..	3,000 7,000	−12.4 −38.6	0.655
Mar. 2, 1905...	3,000 8,000	−14.0 −51.3	0.746	July 4, 1906..	3,000 7,000	2.2 −24.5	0.668
July 6, 1905...	3,000 8,000	0.1 −31.7	0.636	July 5, 1906..	3,000 8,000	2.6 −29.6	0.642
Aug. 3, 1905...	3,000 8,000	8.2 −19.1	0.546	July 6, 1906..	3,000 3.000	− 1.9 −30.7	0.576
Aug. 29, 1905...	3,000 8,000	− 4.7 −37.7	0.660	Aug. 2, 1906..	3,000 8,000	8.0 −25.3	0.666
Aug. 30, 1905...	3,000 8,000	− 4.3 −36.4	0.642	Sept. 6, 1906..	3,000 8,000	3.7 −27.9	0.603
Aug. 31, 1905...	3,000 8,000	− 2.8 −33.7	0.618	Jan. 4, 1907..	3,000 8,000	− 5.1 −38.4	0.666
Jan. 4, 1906...	3,000 8,000	− 8.5 −43.3	0.696	Feb. 7, 1907..	3,000 8.000	−11.4 −51.4	0.800
Feb. 1, 1906...	3,000 8,000	− 8.4 −41.2	0.656	Mar. 7, 1907 .	3,000 8.000	−13.4 −47.2	0.676

TRAPPES.

Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$	Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$
Jan. 5, 1905...	3,000 8,000	− 7.8 −45.6	0.756	Mar. 1, 1906..	3,000 7,000	− 8.3 −42.4	0.852
Mar. 2, 1905...	3,000 7,000	−17.0 −51.0	0.850	July 4. 1906..	3,000 8,000	− 0.2 −31.7	0.603
July 6, 1905...	3,000 8,000	0.6 −27.6	0.564	July 5, 1906..	3,000 8,000	3.2 −27.8	0.602
Aug. 3, 1905...	3,000 7,800	3.7 −23.7	0.573	Aug. 2, 1906..	3,000 8,000	11.7 −19.9	0.603
Aug. 29, 1905...	3,000 8,000	− 5.6 −42.4	0.736	Sept. 6, 1906..	3,000 8,000	0.4 −28.5	0.578
Aug. 30, 1905...	3,000 8,000	− 1.1 −41.6	0.810	Jan. 4, 1907..	3,000 8,000	− 3.2 −41.8	0.772
Aug. 31, 1905...	3,000 7,540	− 4.4 −37.8	0.736	Feb. 7, 1007..	3,000 8,000	−14.6 −57.9	0.866
Jan. 4, 1906...	3,000 7,850	− 5.7 −41.4	0.736	July 4, 1907	3,000 8,000	− 5.5 −34.0	0.570
Feb. 1, 1906...	3,090 8,000	− 4.1 −33.8	0.594				

UCCLE.

Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$	Date.	Elevation.	Temperature.	$\frac{\Delta t}{100 m.}$
July 5, 1906...	3,490 8,460	− 4.0 −43.5	.795	Sept. 5, 1907..	3,492 9,050	0.8 −31.9	.588
Aug. 2, 1906...	2,900 8,240	10.1 −26.4	.683	Jan. 3, 1908..	2,627 8,375	− 9.7 −51.1	.720
Jan. 14, 1907...	2,990 8,550	− 4.5 −40.5	.647	Feb. 6, 1908..	3,000 8,000	− 4.0 −38.9	.698
Feb. 7, 1907...	2,970 7,740	−11.4 −46.3	.732	Mar. 5, 1908..	3,000 7,000	−19.0 −55.7	.917
Mar. 7, 1907...	2,960 8,330	− 7.2 −47.8	.756	July 29, 1908..	3,000 7,700	3.0 −25.2	.600
July 24, 1997 ..	3,428 8,854	2.2 −33.3	.654	July 30, 1908..	3,000 8,000	2.3 −29.0	.626
July 25, 1907...	3,598 8,856	3.2 −31.7	.664	Sept. 3, 1908..	3,000 8,000	−10.6 −42.1	.630

TABLE 2.—*Average vertical temperature gradients between 3,000 and 8,000 meters elevation,* $\frac{\Delta t}{100 \text{ m.}}$

Place.	Summer.	Winter.
Lindenberg	0.699	0.758
Pavlovsk	0.599 (0.625)	0.623 (0.667)
Strassburg	0.626	0.705
Trappes	0.637	0.775
Uccle	0.655	0.745
Average	0.643 (0.648)	0.721 (0.730)

The observations obtained at Uccle are copied from Ciel et Terre, the others from Veröffentlichungen der International Commission für Wissenschaftliche Luftschiffahrt.

The average gradients, exprest in change of temperature in degrees centigrade per hundred meters change in elevation, are given in Table 2. The seventy-two observations upon which they are based are not nearly enough to secure averages free from storm and other irregularities, but probably are sufficient to demonstrate the kind of change in the gradient caused by change of season. As shown by Table 2 the gradient at each of these stations was greater in winter than during the summer, the general average being about 10 to 9.

Two of the gradients found at Pavlovsk were exceptionally low, probably due to unusual local conditions. The numbers inclosed in parentheses give the averages with these exceptional gradients ruled out. The others with them included.

THE FORMATION OF HAIL.

By Dr. J. B. GIBSON. Dated Salisbury, N. C., January 5, 1909.

In the MONTHLY WEATHER REVIEW for January, 1906, 34:30, the Editor has published some observations by Doctor Gibson on the formation of hail, and the following extract from a recent letter presents a slight modification of his earlier views:

It is well known that, as a rule, hail precedes the rain. The general opinion that hailstones have a nucleus of snow I do not believe to be justified. * * * Consider a tumbler of water with all but its central portion turned into crystal ice. This is the natural process in the open air. Before solidification is entirely completed hold the central portion of the glass up at the level of the eye and shake it. A globular mass of unfrozen water and mush ice will be found in the dark central portion. Now let freezing completely solidify the contents of the glass and this central part will be a mass of snow-white striæ radiating in every direction. These streaks are as white as cotton thread. This central white core is what is seen in the hailstone, and is produced by the natural process of freezing the central portion last. I venture to assert that snow will not form at all under conditions such that sleet and hail will be generated readily and abundantly.

THE IMPORTANCE OF SYSTEMATIC OBSERVATION OF PERSISTENT METEOR TRAINS.

By C. C. TROWBRIDGE, D. Sc., Columbia University. Dated September, 1908.

[Reprinted from The Observatory, No. 402, November, 1908.]

The nature of the luminous cloud occasionally seen in the track of large meteors, known as the presistent streak or train, has long been regarded as a mystery by astronomers. Meteors which leave these long-enduring trains are few in comparison to the total number of meteors that are observed, and consequently even experienced observers are sometimes taken unprepared, and fail to record an observation with desired detail. Many trains have been seen, however, which have remained visible from ten to thirty minutes, and definite and authentic facts concerning them have been recorded in numerous cases. The late Prof. H. A. Newton, of Yale University, and Prof. E. E. Barnard, of the Yerkes Observatory, have both published some valuable observations on the drift of trains in the United States, and the late Prof. A. S. Herschel, Mr. W. F. Denning, Mr. T. W. Backhouse, and others have likewise published many important facts relating to presistent trains seen in England. Indeed, a very large part of the progress of meteoric astronomy during the past fifty years is due to the accurate and persevering work of the meteor observers of Great Britain.

Apart from the many recorded observations, only a few brief papers relating to meteor trains have been published. Astronomers appear either to have considered the study of them out of their province, or else for various reasons they have devoted their attention to problems more truly astronomical in nature. The study of presistent meteor trains is highly important, not only because of the general problems relating to the atmosphere of the earth that are involved, but also on account of the bearing of the phenonenon on certain recent discoveries in physics.

It is the purpose of the present paper to show why it is important that every meteor train should be carefully observed and the details of each observation recorded with the utmost accuracy; and to emphasize the fact that owing to the uncertain and sporadic occurrence of meteor trains, the physicist must ever rely on the astronomer for careful and complete records on which to base his deductions. It is obviously necessary that those features of the meteor train which appear to the physicist to be most important should be specially mentioned, and therefore a portion of this paper is devoted to this purpose. Already certain of the features of meteor trains can be explained by the behavior of apparently similar phenomena which have been produced in the physical laboratory. Indeed the results of recent experiments by the writer on gas phosphorescence[1] seems to show that the self-luminous meteor train is also some form of gas phosphorescence. These laboratory experiments necessarily must be referred to in considering the present subject.

Some of the reasons why very careful observation of meteor trains are desirable are briefly as follows:

(1) The drifting motion of meteor trains, so often observed, is unquestionably due alone to atmospheric currents. The observation of these train movements is the only means by which data concerning the motions of the extreme upper regions of the earth's atmosphere can be obtained. In a recent paper over sixty train drifts have been collected, tabulated, and discust, and several facts concerning the atmosphere brought to light.[2] Many of these trains were above 50 miles altitude and recorded by the most accurate meteor observers, Denning, Herschel, Backhouse, Booth, Newton, Barnard, Twining, etc.

(2) A statistical study of trains has shown that many at least of those seen at night are self luminous. The remarkable persistent light of the meteor train is in all probability a gas phosphorescence, since in many respects it is similar to the gaseous "afterglow" which is formed in a vacuum-tube by electrical discharges. This "afterglow," which is a true phosphorescence of the gas, appears greenish yellow when formed in air or nitrogen, and the writer has observed it persist in air for as long as *nineteen minutes* after the discharge had past thru a bulb in which it was formed. The writer has also recently found by laboratory experiments the law of the rate of decay of the luminosity of this phosphorescence. The rate of fading of the light is exprest by a formula of the form

$$I = \frac{1}{(a+bt)^2},$$

from which it follows that the intensity after twenty minutes can be approximately calculated. If the meteor train is the same phenomenon as the "afterglow," or similar to it, and when the fact is taken into account that the meteor train may be half a mile or more in diameter, the long-visible persistence of the phosphorescent train is readily explained by applying the above law of decay. In fact, if the initial phosphorescence of a train is as bright as that artificially formed in the laboratory, the train should be visible for nearly one hour. In the laboratory the discharge tubes containing the glowing gas were only several centimeters in diameter, yet the glowing gas was often visible for many minutes after the electric current was cut off.

[1] Trowbridge, Astrophysical Journal, September, 1907, p. 95–116, figs. 1–9.

[2] Trowbridge, Monthly Weather Review, September, 1907, 35: 390–396, figs. 1–7, tables 1–5.

(3) The duration of air phosphorescence produced in a discharge tube has also been timed under various pressures and other conditions,[3] and the limits of its formation are found to be so definite that if the phenomenon can be proved to be the same as the meteor train, the approximate gas pressure of the atmosphere between 50 and 60 miles height can be obtained, a fact which would be of great value. The "afterglow" has a maximum duration at about 0.1 millimeter of mercury gas pressure. The ordinary limits for long duration appear to be between 0.07 and 0.3 millimeters gas pressure. This of course suggests that the pressure of the earth's atmosphere at about 55 miles altitude, where meteor trains are most persistent, may be 0.1 millimeter.

(4) The so-called expansion of the meteor train almost always observed appears to be gas diffusion. This diffusion is dependent upon the pressure and temperature of the atmosphere at the altitude where the meteor train is formed. It is possible that this diffusion feature of the train will give another means by which the pressure of the atmosphere may be measured, since the theoretical diffusive rate can be approximately calculated, and since the diffusion of the "afterglow" at various pressures can be measured with accuracy. Both the diffusion of the meteor train and of gas phosphorescence is of the order of several meters per second. The "afterglow" or gas phosphorescence diffuses thru the glass vacuum-tubes in which it is formed at this rapid rate.

(5) Meteor trains appear to diffuse more readily in the upper portions of the streak, because many drawings of streaks are conical in form, with the apex pointing downward. Such a form of the streak is to be expected because there would be more rapid diffusion as the pressure of the atmosphere diminished; hence careful drawings of trains are very important to determine if the form is in many cases actually conical, or if the effect is due to perspective only. If the forms are often conical, observations of the different diffusion rates would give atmospheric pressure gradients [at] between 50 and 60 miles altitude.

(6) Many trains have been recorded as appearing like a double line of light, which is explained on the assumption that the luminosity is greatest near the outside of the train, the train thus being tubular. This has an important bearing on the decay of phosphorescence, since the gas afterglow (air) under certain conditions appears to disappear most rapidly where it is formed. Many trains in the writer's meteor-train catalog show this dual appearance of the train.

(7) A record of the total length of track of the meteor and the length and location of the train with respect to the track is important, since it shows the limits of the atmospheric zone where the self-luminous train can be formed and persist.

(8) Careful drawings of the form of trains, either self-luminous or shining by reflected sunlight, at intervals of time after first appearance, would be of value, because frequently the sketch would be found to be a record of some facts concerning atmospheric movements; for example, a sharply-bent train usually indicates a rapid current above or below a relatively calm zone in the atmosphere.

It has been shown by Mr. Denning, Professor Barnard, and others that meteor trains visible to the naked eye for one or two minutes can be seen in the telescope sometimes for over a quarter of an hour. Thus by the use of a low-power mounted telescope, or even a pair of good field glasses, meteor trains

[3] Trowbridge, The Physical Review, 4, Oct. 1906, vol. XXIII. p. 279–306.

can often be studied to greater advantage than by the naked eye alone. The track of every bright meteor should be examined with such a telescope to determine if a faint persistent train remains. It is probable that in this way many persistent trains can be discovered which would not be observed by the naked eye. Moreover, Mr. Denning has shown that a great many meteors are visible in a telescope which are invisible to the naked eye, and he also gives instances where persistent trains of these telescopic meteors have been thus detected. It would also be of great value to use a mounted telescope having a micrometer eyepiece or some device by which the width of the trains could be measured to a fraction of a degree accurately. The same instrument would be of service in locating the position of the train and determining in an accurate manner the rate of drift. Also, since the streak-bearing meteors are fairly well known, watches at adjacent observatories near enough for a good base line could be maintained for the few nights of the year when these meteors occur, for the purpose of doubly observing the train drifts and determining the height of the trains. It is hoped that a definite plan can be formulated for the systematic observation of meteor trains in the future, because they provide the only means by which data concerning the extreme upper regions of the earth's atmosphere can be obtained.

The physicist, by the aid of laboratory experiments, may be able to work out the solution of the meteor-trains problem, but the facts of the phenomena must be observed by the astronomer. The following suggestions are made because it has been found that many records of the past which might have been very valuable have been made of little use by the omission of details in the published reports. It therefore becomes necessary to point out what facts of a meteor-train observation are most important. The facts to be recorded are placed under two headings, because the statements in regard to the meteor nucleus or hot moving body and its train of sparks must be clearly distinguishable in the records from those relating to the true train or streak which remains visible for many seconds or minutes. In many reports there has been confusion in this respect. A third heading might cover various other facts which need not be considered at the time of the observation of the train, but which nevertheless are essential for a complete record. Every one of the following points are important in the record of the observation of a meteor train if they can be noted. *A high degree of accuracy is, however, of the first importance even if it is necessary that the observation be confined to but a few features of the train.*

A. *Observations concerning the meteor nucleus.*

(1) Time of appearance of meteor nucleus and of duration of its flight.

(2) Radiant point and name of meteor (Leonid, Perseid, etc.).

(3) Color of nucleus, length of track, and length of portion of streak with respect to the entire track.

B. *Observation of the persistent train or streak.*

(4) Color of train immediately *after* disappearance of nucleus and *any change of color* of the train during the time that it is visible.

(5) Length and width of train, in degrees and minutes of arc, immediately after disappearance of nucleus, and its position in the heavens with respect to easily identified stars.

(6) Observations, at short intervals of time, of the change of dimensions of the train in degrees, accompanied by a series of the drawings, if possible, indicating the successive changes in shape of the train. *The width of the train*, or a portion of it, *at successive intervals of time*, is of the greatest importance, since it indicates *the rate of diffusion of the gaseous mass.*

(7) The displacement or drift of the train in degrees, with corresponding time. For this purpose some *bright portion of the train* should be selected *when the train is first seen.* Also the direction of the drift with *respect to the earth's surface*, and if calculations are made of the rate in miles, they should be so stated.

(8) If the intensity of light of the train is (1) uniform, (2) brightest on the outside, or (3) brightest at the center, and the time of this observation after the first appearance of the meteor.

(9) Whether the train increases in brightness, this effect appears to occur not infrequently. The observer should be careful not to mistake an increase in the dimensions of the train for an increase in intensity.

(10) Spectroscopic observations, looking for the presence and position in the spectrum of one yellow line and one or two lines in the green.

(11) How long the train is visible to the naked eye and how long visible in the telescope.

Systematic and accurate observations of persistent meteor trains will in all probability lead to results of much practical value. It is within reason to hope that light may be thrown on the following problems: (1) The cause of the apparent self-luminosity of the meteor train; (2) the height of the earth's atmosphere, by accurate measurement of telescopic trains; (3) the density of the earth's atmosphere at an altitude of 50 to 65 miles, by a direct comparison with the pressure at which gas phosphorescence can occur if the meteor train is an "after-glow;" (4) the direction and velocity of currents in the atmosphere at great altitudes; (5) the possible relation of atmospheric motion at high altitudes to barometric pressure, and some other facts which seem indicated by the statistical work done by the writer which require further data for confirmation.

TRANSFORMATIONS OF SNOW CRYSTALS.

By A. ERMAN. Dated, 1859.

The following extract, here reprinted from the London Philosophical Magazine, 1859, **17** (4th series): 410–413, presents some observations on the transformations of snow crystals, made by A. Erman during his trip around the world. They were published in his Reise um die Erde[1] and translated by him for Tyndall, who published them in the above journal. We omit the figures given in the London Philosophical Magazine.—*C. A.*

May 13, [1829?] Latitude 60° 40′, longitude 138° 57′ east from Paris, at 2580 Parisian feet (2749 English) above the sea.—I had begun immediately after noon to measure solar altitudes, when a number of light clouds began to form and then to be driven fast by the west wind. The air cooled down (from about +3° R. [38.8° F.]) to +1° R. (34.2° F.), and snow fell for sixteen minutes; then the clouds dissolved again, the evening became clear, and the cold increased in the night to −5° R. (20.8° F.). I have never seen snow in more perfect and variously formed crystals than during this short and sudden shower. Each grain fell single, and among the few which settled on the glass or the metal of my instruments, I could distinguish six different forms. Doubtless many more remained unobserved, for my attention was drawn in the meantime to a more wonderful and quite novel phenomenon. Many of the crystals began to melt the instant they touched a solid body, and some, as it seemed to me, melted while still falling thru the air; but in the next moment this was followed always by a new congelation, the grain of snow assuming, not its previous form, but another more complex. Thus, for instance, the most simple crystals which I observed to-day, consisting of six thin needles of ice, which adhered to each other like the diagonals of a regular hexagon (fig. 2*a*). When melting, each single ray of this star contracted into a thicker cylinder of water, having about half of its former length

[1] Ermann: Reise um die Erde, 1835–1849, Hist. Abth, **2**:395; or the English translation, abridged, Travels in Siberia. London, 1848. **2**:501.